Initial Results from the DS1/IPS Diagnostics Sensors (IDS)

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Goal for IDS

- **Understand the local environment on a spacecraft utilizing an Ion Propulsion Subsystem (IPS)**
  - What is the nature of the CEX plasma?
  - What is the IPS contamination environment?
  - Are there EMI/EMC concerns?
  - Are IPS DC-magnetic fields compatible with science measurement requirements?

IDS Approach

- **Execute a balanced investigative effort that includes the following**
  - Flight measurements with integrated sensor package
  - Ground laboratory measurements for correlation
  - Models describing physical principles and mechanisms
- **Provide the user community with results and models for planning future IPS missions**

IDS Team Members

- JPL
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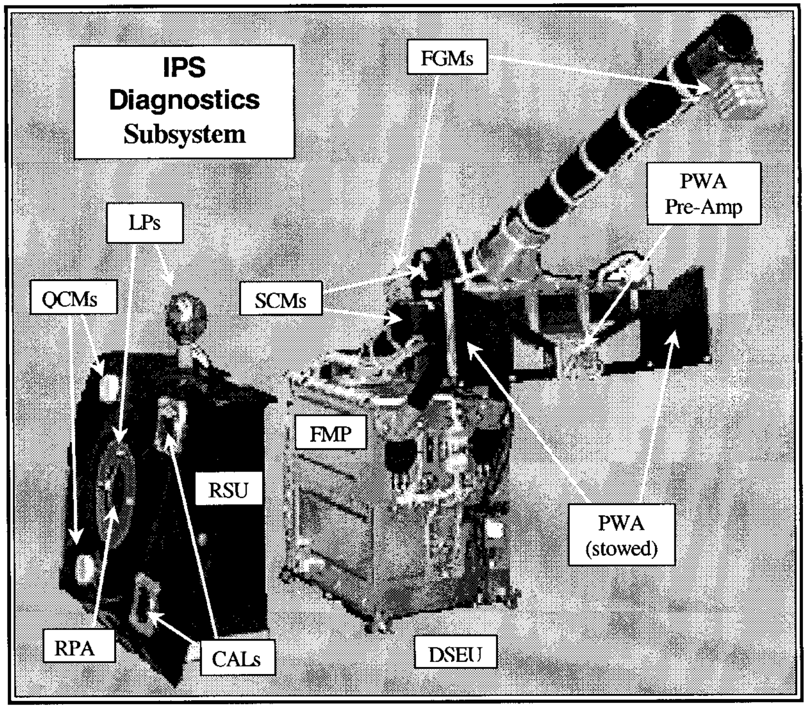
  - Modeling: J. J. Wang
- Technical University of Braunschweig
  - FGM: G. Musmann, I. Richter, C. Othmer, K-H. Glassmeier
- TRW
  - PWS: S. Moses, R. Johnson
- Maxwell Technologies
  - Modeling: I. Katz, V. Davis, B. Gardner
- Physical Sciences, Inc.
  - DSEU, Calorimeters: E. Lund, P. Joshi, M. Hinds, B. D. Green

IDS Flight Hardware

- **IDS is a compact, highly-integrated sensor suite**
  - **Mass: 8 kg**
  - **Power: 21W , 7W (standby)**
  - **Spacecraft Interfaces:**
    - 28 VDC (±6 VDC), MIL-STD-1553B
- **IDS samples continuously**
  - **RSU sensors at 2 second intervals**
  - **FMP scans at 16 second intervals**
  - **Waveform transient recording**
    - PWA, SC at 20 kHz, 1 second
    - FGMs at 20 Hz, 55 seconds



Remote Sensors Unit (RSU):
Plasma: 2 Langmuir Probes(LPs), Retarding Potential Analyzer (RPA)
Contamination: 2 Quartz Crystal Microbalances (QCMs), 2 Calorimeters (CALs)
Diagnostic Sensors Electronics Unit/Fields Measurement Processor (DSEU/FMP):
Electrostatic Fields: 2-m dipole Plasma Wave Antenna (PWA) with pre-amplifier
Electromagnetic Waves: 2 Search Coil Magnetometers (SCMs); 1 failed before launch
DC Magnetic Fields: 2 ea. 3-axis Flux-Gate Magnetometers (FGMs)

IDS Sensor Performance

- **IDS sensors calibrated over operating temperature range (-25°C to +55°C)**
- **Measurement capabilities summarized below**

Sensor	Measurement	Range	Resolution
QCMs	Mass/area	0 to 500 $\mu g/cm^2$	0.005 $\mu g/cm^2$
CALs	Solar Absorptance (α) Hemi. Emittance (ε)	α = 0.08 (BOL) to 0.99 ε = 0.05 to 0.85 (BOL)	$\Delta\alpha$ = 0.01 $\Delta\varepsilon$ = 0.01
LPs	Probe Current Probe Voltage	I =-0.4 to 40 mA V = -11 to +11 VDC	1% 1%
RPA	Current (Gain Select) Grid Bias Voltage	I = 0.01, 1, 10, 100μA V = 0 to +100 VDC	1% 0.4V
PWA	E-field (Adjust. Gain) 24 Freq. Channels *	50 to 160 dBμV/m 10 Hz to 30 MHz (4/decade)	± 3 dBμV/m ± 40% (-3dB)
SCM	B-field (Adjust. Gain) 16 Freq. Channels *	80 to 160 dBpT 10 Hz to 100 kHz (4/decade)	± 3 dBpT ± 40% (-3dB)
FGMs	Magnetic Field Vector **	±25,000 nT	0.5 nT

IDS Configuration on DS1

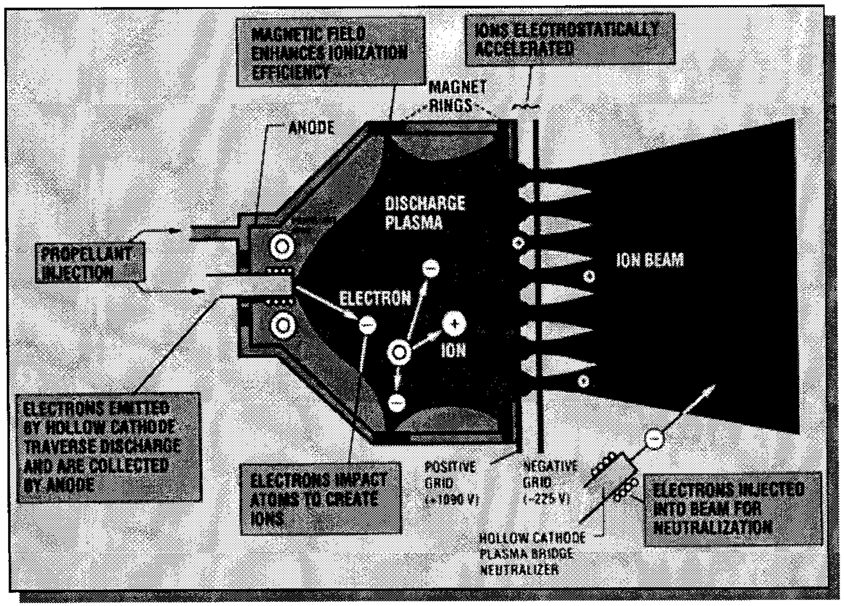
- DSEU in shade
- Boom assembly, PWA in sun
- RSU sensors 45° from sun
- Direct line-of-sight to IPS grid for lower pair of contamination monitors (CMs)
- Upper CM pair is shadowed from IPS

IPS Operation and Charge Exchange Xenon Ions

- **IPS produces beam and cold, dense plasma flow**
  - IPS ionizes 70% to 90% of xenon in discharge chamber
  - Fast beam ion strips electron from slow thermal xenon atom

    $$Xe^{+}_{beam} + Xe^{0}_{therm} \longrightarrow Xe^{0}_{beam} + Xe^{+}_{CEX}$$

  - "Charge-exchange xenon" (CEX) ions driven by local E-fields

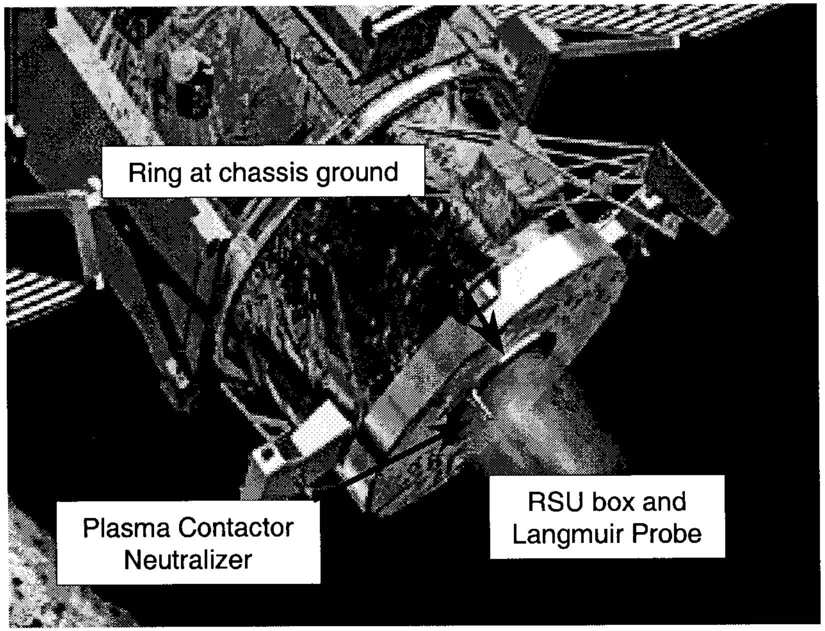


- **CEX ions affect these environmental factors**
  - S/C potential
  - Contamination
  - Plasma noise

IPS Current Balance on DS1

DS1/NSTAR Diagnostics Package

JPL NASA TUB TRW



- Current balance determines the net charge on DS1
- Net charge determines the DS1 chassis potential with respect to solar wind "ground"

- Key contributors to current balance on DS1 are:
  - IPS ion beam
  - IPS neutralizer
  - Spacecraft chassis (IPS thruster mask ring)
  - IDS Langmuir Probes with conductive black Kapton MLI on RSU

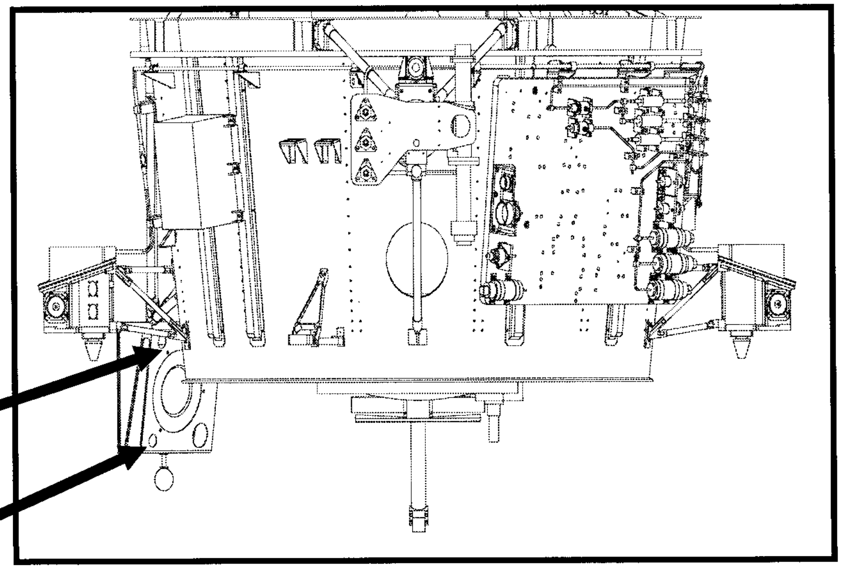
IPS Plasma Effects

- **IPS CEX plasma current collection drives the DS1 chassis from -6 to -10 V relative to space "ground"**
  - Current collection affected by plasma density and electron temperature (1.2 to 2.0 eV)
  - CEX ions from IPS plume "orbit" DS1
- **Significant CEX ion flux detected by PEPE during IPS operations**
- **Solar wind proton measurements by PEPE essentially unaffected by IPS operations**
  - Effects on solar wind electrons not quantified

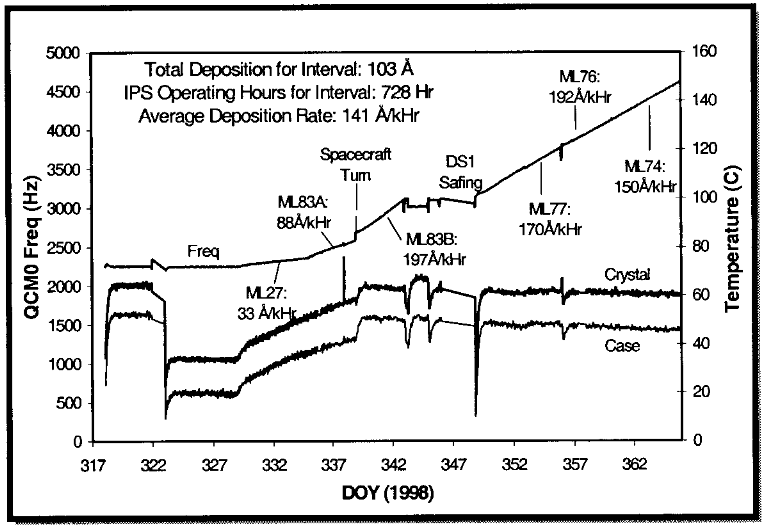
Contamination from IPS

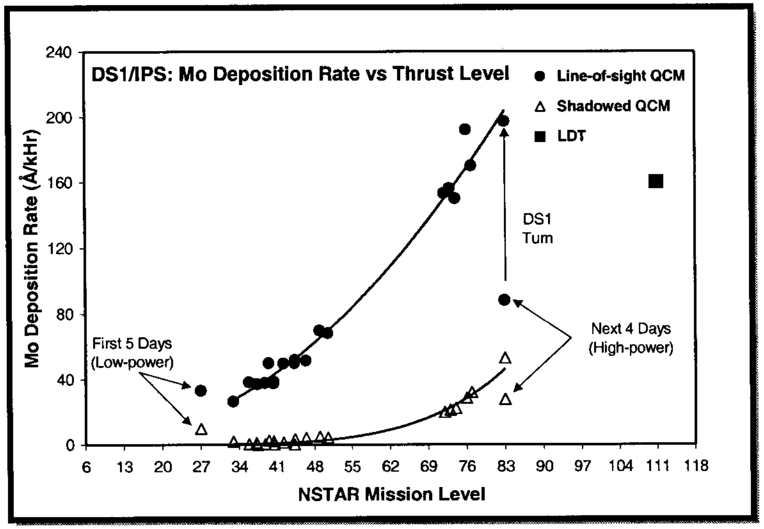
- **IPS wear out mechanism is grid erosion**
  - CEX ions accelerated into outer grid (-150 to -250V)
  - Grid material (molybdenum) is sputtered by CEX ions
  - Sputtered material can collect on nearby surfaces
  - Ionization of Mo atoms in plume leads to non-line-of-sight transport and deposition

- **RSU configuration on DS1 yields 2 distinct contamination monitor environments:**
  - Shadowed region, shielded by spacecraft structure
  - Direct line-of-sight (LOS) to IPS thruster grid



IDS Contamination Measurements





- **Mo deposition readily detected by QCMs**
  - Line-of-sight deposition shown in figure to left is >10x shadowed sensor
  - Sun-orientation effect on deposition for ML83A/B (DOY 98-335 to 98/344)
- **IPS thrust level affects Mo deposition rate**
  - Correlates with current collected by outer grid
  - Highest IPS levels only at beginning of mission
  - Ground test result is for maximum thrust level

IPS Contamination Effects

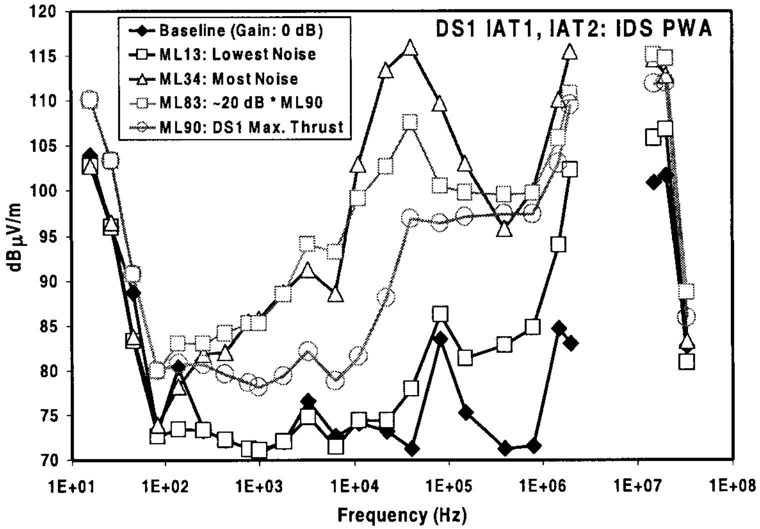
- **Line-of-sight deposition rate correlates with long-term ground test experience**
  - 25 nm Mo accumulation after 3500 hours IPS operation
  - Expect highest grid erosion early in operating life
  - Extrapolating DS1 rate to ground results is difficult
  - Surface thermo-optical properties changed rapidly for line-of-sight ($\Delta\alpha/\varepsilon$ ~ 0.3 in 5 days at ML83)
- **Non-line-of-sight deposition effects minor**
  - 2.5 nm Mo accumulation after one year
  - Chamber effects invalidate ground correlation
  - Effect on SCARLET arrays is immeasurably small due to geometric effect (ions are likely to be repelled by positive array voltage)

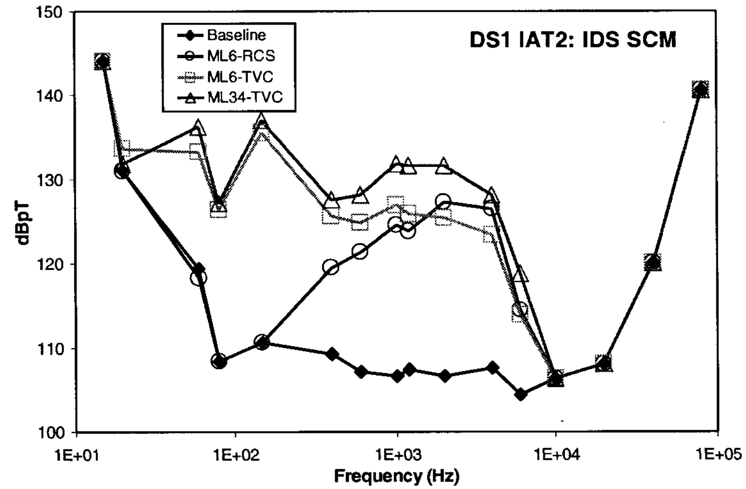
IPS EMI/EMC

- **Hollow-cathode discharge plasma sources produce substantial electrostatic noise**
  - Electron density fluctuates with discharge instabilities
  - CEX plasma serves as conductive medium for noise
- **IPS produces momentary arcs during ignition and "recycle" events**
  - Ionization arcs between grids causes IPS to cycle beam power supplies
- **Plasma plume and beam extend over large distances (km) from IPS**
  - Potential for interference with RF telecommunications link

IDS Plasma Wave Measurements

- **Plasma Waves**
  - <120 dBμV maximum
  - IPS ignition or recycles produce peak amplitude signals comparable to hydrazine thruster firings (<140 dBμV/m)
- **EMI**
  - IPS produces EM noise (<140 dBpT @ 2 kHz)
  - Ion engine gimbal motors for TVC produce similar EMI levels at 100 Hz
  - IPS has no impact on telecommunications link

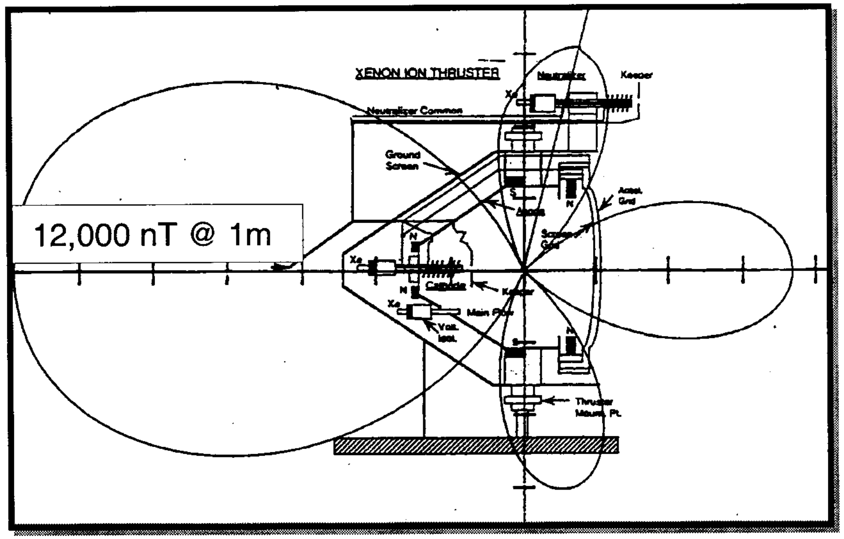




IPS DC Magnetic Field

DS1/NSTAR Diagnostics Package
JPL NASA TUB TRW

- **SmCo magnet rings in IPS thruster**
  - "Ring-cusp" geometry to improve IPS xenon ionization efficiency
  - External fields >10,000 nT at 1 meter distance
  - Temperature dependence characterized in flight



- **Magnetic field stability and science measurements**
  - Temperature-corrected DC fields stable within 5 nT after 1 year operation (< 0.1% change since launch)
  - No long-term degradation of magnetic fields apparent
  - Short-term magnetic field stability allows measurement of fluctuations (> 1 nT) of external B-fields

IDS Conclusions

- **IPS local environment well-characterized**
  - **CEX plasma affects DS1 chassis potential**
    - CEX ions surround DS1, substantial ion flux for particle spectrometers, solar wind protons unaffected
  - **Line-of-sight contamination environment is severe**
    - Non-line-of-sight contamination is substantially less
  - **Plasma waves are produced by IPS**
    - Peak amplitudes are equivalent to other sources on DS1 (hydrazine thruster firings, gimbal motor operations)
- **Further investigations in progress**
  - **Effects of sun-orientation on chassis potential**
  - **Long-term contamination rates vs IPS ML**
  - **Plasma wave noise dependence on IPS operating conditions (Why is ML90 much quieter than ML83?)**